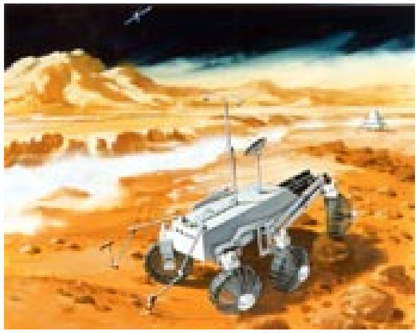
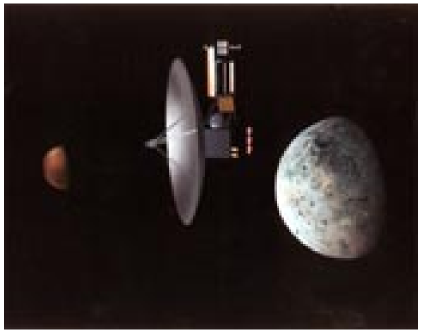
2nd DARPA Fault-tolerant Computing Workshop

Remote Exploration and Experimentation (REE) Project



Autonomous Robotic Vehicles



Deep Space Exploration

High Data Rate Instruments

Robert Ferraro

Manager, REE Project

Center for Space Microelectronics Technology

REE Context

Rad-hard processors today are 5 - 10 years behind the commercial state of the art, and are *continuing* to fall farther behind ....

The commercial computing industry is over a hundred times larger than the entire space and defense electronics industry, *and has no interest in space at all !*

Instrument Data Rates continue to increase dramatically, while bandwidth to the ground remains stagnant

Mission cost caps are driving spacecraft sizes smaller and power budgets lower, and are putting severe cost pressure on ground operations

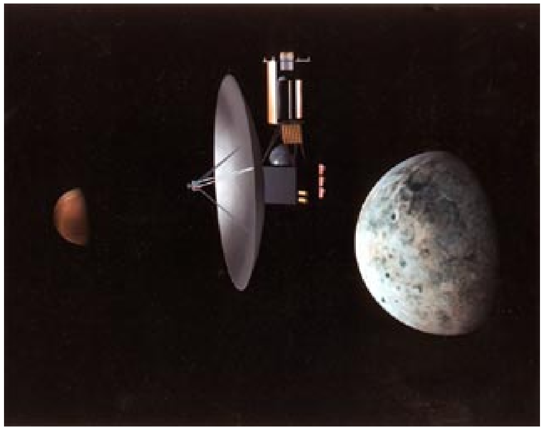
The Federal High Performance Computing and Communications (HPCC) Program has demonstrated that supercomputing capability can be obtained by leveraging Commercial Off The Shelf (COTS) Technologies

→ *REE will leverage HPCC program experience to bring state of the art commercial computing capabilities into space*

REE Goals/Approach

Vision:

Move Earth-based Scalable Supercomputing Technology into Space



REE Goals/Benefits

- **Drive the development of low power, scalable, fault tolerant spacecraft computers in partnership with Industry**
- **Enable a new class of science missions by the availability of high performance spaceborne computing**

REE Approach - Partner with Industry and Academia

- **Develop and Validate 300 - 1000 Mops/Mflops per watt technologies**
- **Develop scalable fault tolerant *systems* which degrade gracefully**
- **Demonstrate a new class of onboard applications in partnership with NASA Scientists and Mission Managers**

Project Structure

Vertically Integrated Work Breakdown Structure

Applications Challenge Teams
Applications range define the limits to be addressed

System Software Support
How do we reliably use COTS parts in space?

Scalable Low Power Embedded Architectures
Power Performance is the Key Metric
Maximum leverage of COTS essential

'02 - '03 Timeframe System Goals

- > 300 MOPS/watt (32 bit mixed integer & floating point OPs) → ***>100 X Mars Pathfinder***
- Scalable architecture from 1 to at least 50 nodes
- Power required scales with # of nodes to 100 watts (30 GOPS)
- Applications achieve 50% of architecture peak performance on average
  Fault tolerance overhead not included

Applications Range Drive Architecture

Micro-rovers

- 1-2 computing nodes, 2-5 watts power budget
- REE would enable autonomous operation, consisting of
  - *stereo vision*
  - *feature identification*
  - *terrain path planning*
  - *experiment control & analysis*
  - *vehicle motion control*

Hyperspectral Imagers

- 100 watts & 30 GOPS
- 20+ megasamples/sec @ 12 bits
- Processing driven by bandwidth limited communications (get the best bits back)
  - *1st level data corrections*
  - *cloud editing*
  - *atmospheric correction*
  - *change detection*

Command & Control Functions

- Real time, guaranteed correct results, but relatively low OP counts

REMOTE EXPLORATION AND EXPERIMENTATION PROJECT

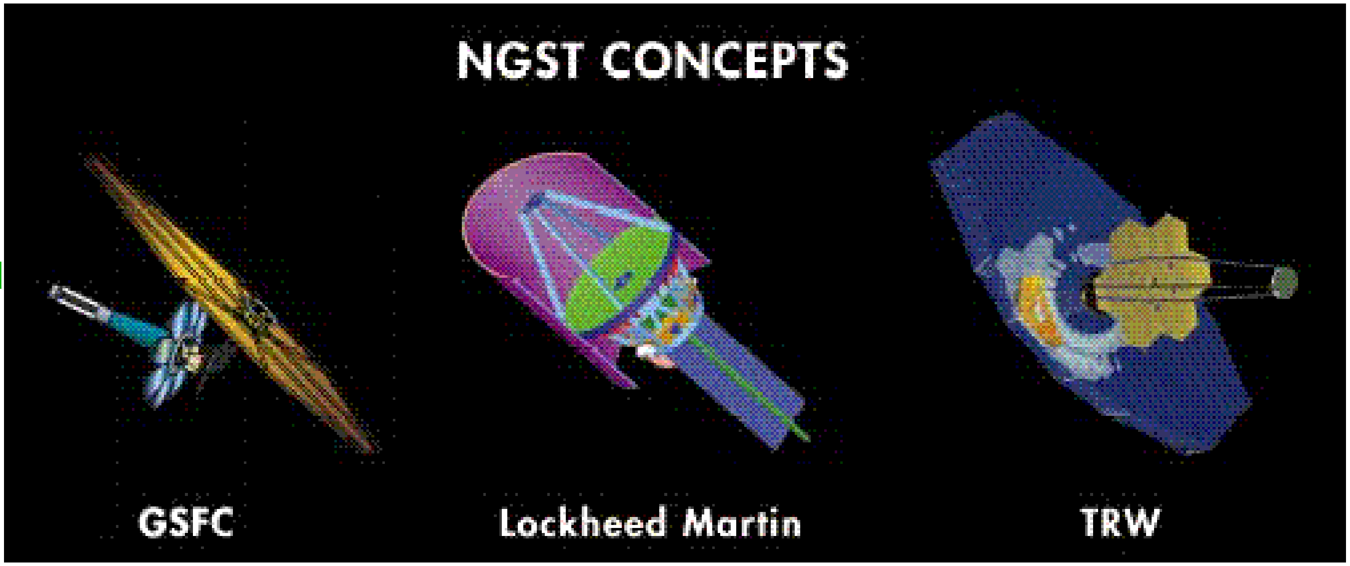
HPCC

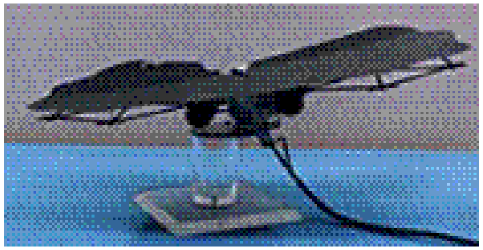
Next Generation Space Telescope Team

REE Principle Investigator: Dr. John Mather, NGST Study Scientist

SCIENCE OBJECTIVES

- Study the birth of the first galaxies
- Determine the shape and fate of the universe
- Study formation of stars and planets
- Observe the chemical evolution of the universe
- Probe the nature of dark matter





TECHNOLOGY HIGHLIGHTS

- *Precision deployable* and inflatable structures
- Large, low areal density cold active optics
- Simulation based design
- Passive cooling
- *Autonomous operations and onboard scheduling*

NGST Challenge Applications

Image Processing

- Multi-read infrared detector readout and signal processing
  - *Large gains in data compression and lowered noise appear possible*
  - *Will require 100-1000 reads per pixel (up to 0.6 Gpixels per sec) and an algorithm to detect and eliminate cosmic rays*
  - *With 100 million pixels, even a modest number of samples per second demands compute capability of Gflops or more*
  - *Computer memory needs to be large compared with the number of pixels(>1 GB)*

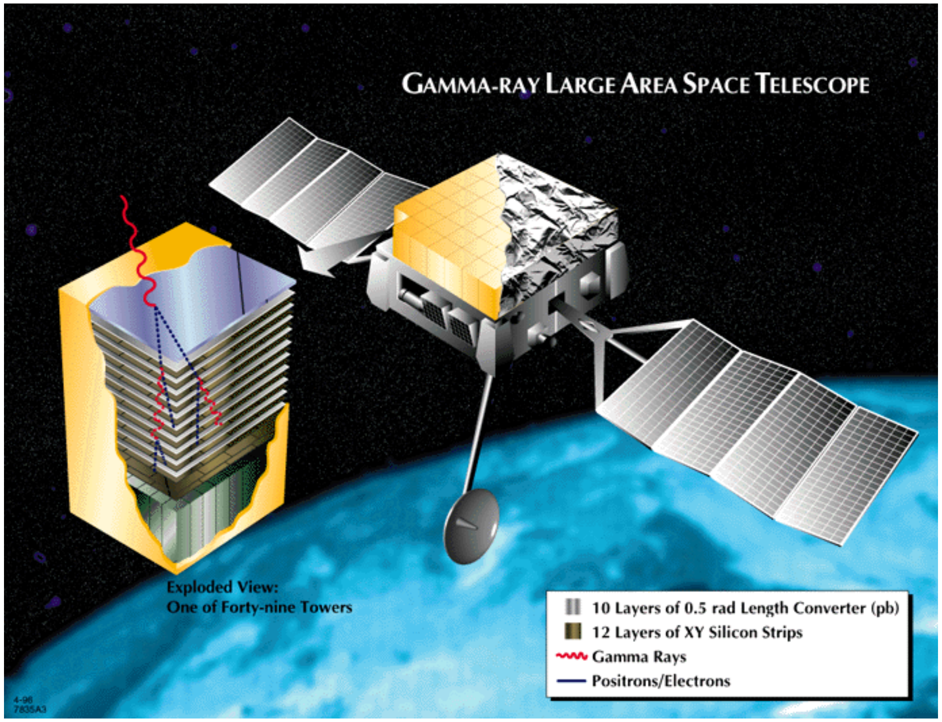
On-Board Optical Alignment Control System

- Algorithm iterates over taking images and moving actuators until the required wavefront quality is achieved
  - *Observe a set of images at multiple field positions and multiple wavelengths*
  - *Estimate wavefront error using some combination of phase retrieval and interferometric techniques (> 1 trillion FLOPS / image)*
  - *Determine actuator motions which minimize the wavefront error*
  - *Move the optics and the actuators*
  - *Repeated cycle until an acceptable rms wavefront error tolerance is reached*
- Current NGST plan is to use a supercomputer on the ground

Gamma Ray Large Area Space Telescope

REE Principle Investigator: Prof Peter Michelson, Stanford University GLAST Principle Investigator

- GLAST will probe active galactic nuclei (spectral shape and cutoff), study gamma-ray pulsars, respond in real-time to gamma-ray bursts.
- GLAST will produce 5-10 Megabytes per second after sparse readout, mapping into 50 MIPS of computing requirements to meet the requirements for the baseline mission.
- New science addressed by GLAST focuses on transient events of a few days in AGNs and .01–100 seconds in gamma-ray bursts.
- REE could enable GLAST to produce 10x this data volume if it were to do most of its background discrimination in software. This would allow real-time identification of gamma-ray bursts, and permit the mission scientists to extract secondary science from the "background."



GLAST is a high-energy gamma-ray observatory designed for making observations of celestial sources in the range from 10 MeV to 300 GeV.

Using COTS Technology in Space

Issue

- COTS in space means SEU susceptibility

Approach

- Characterize the fault-tolerance environment for COTS parts in space
- Characterize the range of application fault tolerance requirements
  - *Bit flips in data look like noise in the instrument*
  - *Bit flips in program code are typically process fatal!*
  - *Bit flips in arithmetic and constants are usually non-fatal, but produce wrong results*
- Develop system software which will provide fault tolerance in a scalable multiprocessor computer system which supports real-time operation
- Develop mechanisms to support multiple levels of fault tolerance
  - *Simplex: Restart only for non-critical tasks*
  - *Duplex: Compare and restart only - for correct results which are not time critical*
  - *Triplex: Operate through*
- Develop application program interfaces (API's) and tools to support software-implemented fault-tolerance (SIFT) techniques
- Validate SIFT techniques by testing and experimentation

DARPA DRC

DARPA Distributed Reliable Computing - REE Interest

- REE will pursue COTS based non rad-hard scalable architectures
- Reliability to be dealt with at the system level (hardware+software)
- Graceful degradation a key feature
- No critical components / No single points of failure

REE System Software focus - Software Implemented Fault Tolerance

- Application selectable levels of fault tolerance
  - *simple restart*
  - *check point/role back*
  - *operate through*
  - *potentially interested in real-time operate-through*
- Distributed real-time fault tolerant OS

Potential REE leverage of DARPA investments

- Extend for reliable MPI ?
- Insert into commercial RTOS ?
- Expanded SIFT testbed at JPL ?

Conclusions

Maximum COTS Leverage is Essential

- Entire Federal and Commercial Space Electronics Investment is Dwarfed by Commercial Computing Industry
- Radiation Hardening is Prohibitively Expensive and Time Consuming
  - *Parts are obsolete by the time they become available*
  - *Maintaining the software tools base is problematic, since commercial vendors have moved on at least two microprocessor generations!*
- COTS Capabilities Still Expected to Double Every 18 Months for the next 10 Years

NASA Power Constraints are Unique Among Spacefaring Concerns

- DOD Missions are Survivability Driven, with Power a Secondary Concern
- REE Must Push on Power, Since No One Else Will

Riding the COTS Technology Wave Appears to Be Possible, *But We Will Have To Deal With Nondestructive Faults in Software*

Investments/Leveraging of some key ultra-low power computing technologies is needed to be successful

REMOTE EXPLORATION AND EXPERIMENTATION PROJECT

HPCC

Schedule Overview